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PERCEPTION OF AIRCRAFT SEPARATION WITH PILOT-PREFERRED SYMBOLOGY ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

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SUMMARY

The concept of a cockpit display of traffic information (CDTI) includes the integration of air traffic, navigation, and other pertinent information in a single electronic display in the cockpit. The present study was conducted as part of a project directed toward developing a clear and concise display format for use in later full mission simulator evaluations of the CDTI concept. This experiment required pilots to choose their preferred method of displaying air traffic information for several variables. Experimental variables included: type of background, update rate, update type, predictor type, and history type. In Phase 1, each pilot designed a display he felt would be most useful in flight operations. After a series of test trials, each pilot was given the opportunity to modify the display for the experimental task. For Phase 2, the pilots returned for a second day of testing. At that time they repeated the experimental task using their display as well as displays chosen by other pilots. Results indicated a variety of individual preferences in symbology and differences in the accuracy of judgments. Pilots indicated concern for clutter of the display, relationship of the displayed symbology to physical reality, and a need to perceive the relative motion of the intruder aircraft. Despite differences in preferred symbology, there appeared to be a consensus among pilots in the use of the symbols for display interpretation. Analysis of data indicated that pilots were able to improve their performance with practice, and that those displays which used only curved predictors resulted in fewer errors compared to displays with only ground referenced history.

INTRODUCTION

Increased air traffic necessitates the finding of new ways to manage air space. The cockpit display of traffic information (CDTI) is one proposed method of partially dealing with this increasingly important problem. This experiment is the eighth in a series of experiments aimed at the development of a clear and concise generic display. Previous experiments have studied methods of depicting past and future position of the aircraft and the effects

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This work was performed under Grant NSG 2269 at San Jose State Univ.

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of varying time to encounter, different viewing times, and update type and rate (refs. 1-3). It was found that a major source of variability was directly attributable to differences in subject performance. It was anticipated that if pilots were given the option of designing their own displays, they would ultimately select the symbology that would be optimal for their own use. This would be reflected by improved performance in the experimental task. The experimenters were interested in determining the strategies the pilots used to interpret the displays, and whether there would be a consistent strategy across pilots, despite any display differences.

The primary questions to be answered in this paper are: 1) what combination of display symbology would pilots choose for their own use? 2) would the display selected for actual flight differ from that chosen for best performance on this experimental task? 3) does use of their own chosen display improve performance? 4) what strategy is used for display interpretation? and 5) what consistencies are present between strategies?

METHOD

Display Hardware

The CDTI was displayed on an 18 cm by 18 cm cathode ray tube (CRT) located directly below the attitude indicator in a fixed-base cockpit simulator. The center of the display was 25° (0.44 rad) below the horizontal and 0.87 m from the pilot's eye-reference point. The display symbols were generated by a general purpose, stroke-writing computer graphics system. The green phosphor on the CRT left no noticeable afterglow.

Display Symbology

A chevron symbol for own-ship and a circular symbol for the intruder remained constant for the experiment. These symbols were preferred by most pilots in Hart's study of pilot opinions on various types of CDTI symbols (ref. 4). The width of the terrain displayed on the map was always 10 n. mi. With this map scale, which seems reasonable for terminal area operations, 1 n. mi. on the ground equals 1.2 cm on the display. The display was always heading up so that, as the display updated, the map rotated under the fixed own-ship symbol. No sensor noise or tracker lag was simulated for these tests.

The independent display variables included: 1) background, 2) update type, 3) update rate, 4) predictor type, and 5) history type. Refer to table 1 for a detailed description.

Figure 1 shows the eight parameters that were used to specify an encounter between own-ship and an intruder.

TABLE 1.- DISPLAY OPTIONS AVAILABLE TO THE PILOTS
FOR DISPLAY DESIGN

Background: 1. None 2. Flightpath: an RNAV route with runway symbols 3. Grid: pattern of lines intersecting at right angles
Update type: 1. Rotation, translation, and update of own-ship 0.1 sec; intruder update 0.1, 1, 2, or 4 sec 2. Rotation of map 0.1 sec, translation and update of own-ship and intruder the same at 0.1, 1, 2, or 4 sec
Update rate: 1. 0.1 sec (continuous) 2. 1 sec 3. 2 sec 4. 4 sec
Predictor type: 1. None 2. Ground-referenced straight: future position over the ground with the provision that the aircraft maintains its current ground track 3. Ground-referenced curved: future position over the ground with the provision that the aircraft maintains its current turn rate 4. Relative: future intruder position relative to own-ship, assuming that both aircraft maintain their current ground track
History type: 1. None 2. Ground referenced: past position over the ground represented by a "dropped" dot every 4 sec for a total of 32 sec 3. Relative: past position of the intruder relative to own-ship across the face of the scope

In Phase 1 of this experiment, the separation distance (R) was an independent variable and was either 914 m (3000 ft) or 1829 m (6000 ft). In Phase 2, the separation distance was held constant at 914 m (3000 ft). There were no encounters that would result in a collision. For the experimental task, 24 encounters were viewed. In 12 of those encounters the intruder would ultimately pass in front of own-ship. Figure 2 depicts those 12 encounters and the parameters as they would appear using the curved ground-referenced predictor and history. The other 12 encounters differed from these only in that the intruder would ultimately pass behind own-ship.

Task

In Phase 1, the pilot's task was to monitor a CDTI and select the display symbology he felt was optimal for use in actual flight. For each

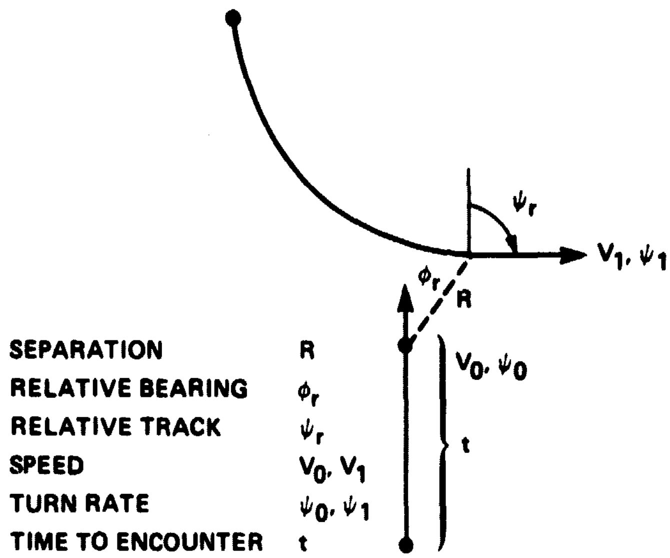

Figure 1.- Parameters used to specify an encounter between own-ship and intruder.

level of each variable, pilots viewed as many encounters as was necessary for them to make a decision. The design of the display was followed by two test trials of 24 encounters each. These were presented with a 914 m (3000 ft) or 1829 m (6000 ft) miss distance. During this portion of the experiment, pilots were asked to predict whether an intruder aircraft would pass in front or in back of own-ship. Each trial was initiated by the pilot pushing a start button. Four seconds after the display began updating, the intruder appeared on the screen with a position, velocity, track angle, and turn rate calculated so that the intruder would be either directly in front or in back of own-ship at 0 sec to encounter point. Sixteen sec after the intruder appeared, the screen was blanked and replaced with a message asking whether the intruder would pass in front or in back of own-ship. The pilot indicated his decision by pushing one of the two buttons on a handheld switch. The words 'IN FRONT' or 'IN BACK' then appeared indicating the correct decision.

During Phase 2 of experimentation, pilots monitored each CDTI design for 24 encounters. At that time, pilots saw their own display as well as those chosen by the other pilots.

Subjects

Six male airline pilots served as paid subjects. They were selected from a pool of pilots who have volunteered to participate as test subjects. Four of the pilots had participated in previous experiments which used CDTI symbology. Each level of the display variable was explained during the course of the experiment.

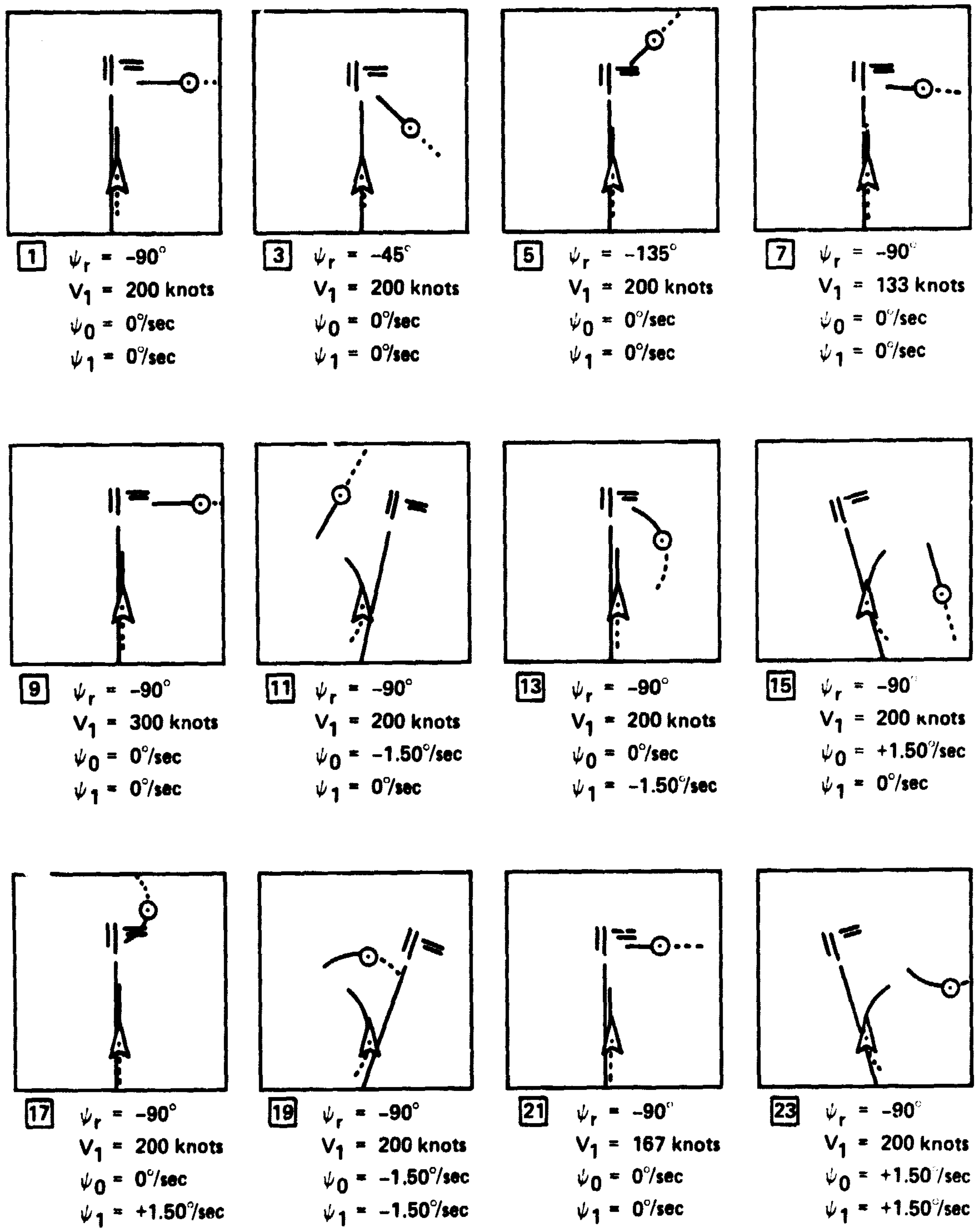

Figure 2.- Twelve of the 24 encounters in which the intruder passes in front of own-ship. In these displays both own-ship and intruder have ground-referenced history and a curved ground-referenced predictor.

PHASE 1

The primary objective of Phase 1 was to determine the type of display symbology pilots would choose if designing a CDTI for their own use. Because of the wide variability of pilot performance in earlier experiments, this experiment was designed to see if an individual pilot's performance would be better on a display he designed himself. Of additional interest were strategies the pilots used to interpret the different displays.

Independent Variables

Table 1 lists the display variables used in this experiment. These were available in any combination. After completing the display design and the subsequent experimental task using their own choice of display elements, pilots were asked their opinions concerning map orientation, predictor length, viewing time, and strategy they used to interpret the displays. These were not available as part of the display design choices but asked for future reference (see table 2 for detailed description).

TABLE 2.- DESCRIPTION OF ADDITIONAL DISPLAY QUESTIONS

Map orientation: 1. Heading up: the map rotates so that own-ship's heading is always up 2. North up: the map does not rotate and is oriented so that north is up
Predictor length: 1. 32 sec: predicts where the aircraft will be in 32 sec with the provision that it maintain its current turn rate 2. 60 sec: predicts where the aircraft will be in 60 sec with the provision that it maintain its current turn rate
Viewing time: 1. 16 sec: encounter begins at 60 sec to encounter point (this viewing time was used for all test trials) 2. 8 sec: encounter begins at 52 sec to encounter point 3. 4 sec: encounter begins at 48 sec to encounter point 4. 2 sec: encounter begins at 46 sec to encounter point 5. 1 sec: encounter begins at 45 sec to encounter point

Experimental Design

Each of the six pilots was shown all levels of the five display categories as listed in table 1. One variable was covered at a time. Each pilot could view the options as often as he wished. After making a choice for one variable, the same procedure was used for the next variable. If at

any time the pilots wanted to review a prior choice and possibly make a change, they were allowed to do so. The instructions for this first step required that pilots make their choices based on what they would like to see as part of an actual cockpit design. After this step was completed, the pilots performed the separation monitoring task using the preferred display. They were then given the option of modifying their design to make their design optimal for performing the separation monitoring task. The task was then repeated. The monitoring task consisted of two blocks of 24 encounters. The two blocks varied only in the miss distance, which was 914 m (3000 ft) or 1829 m (6000 ft). Miss distance was randomized over blocks and encounter order was randomized within blocks.

Results

Tables 3 and 4 indicate the initial display symbologies chosen by each pilot and any subsequent modifications made for this specific task. Of the six pilots, three made changes in their display: pilot 1 from no predictor and ground-referenced history to ground-referenced predictor on both aircraft and no history, pilot 4 from ground-referenced predictor on the intruder only to ground-referenced predictor on both aircraft, and pilot 5 from no history to ground-referenced history on only the intruder aircraft. The percent error for each pilot on his displays for each portion of the task is presented at the bottom of the respective tables. Results indicate that performance improved with a larger miss distance on the second task. The opinions from the questionnaire indicated that the pilots liked the information which could be provided by a CDTI. It was felt that this information could be best used to aid in the visual acquisition of nearby aircraft.

Pilot opinions were requested concerning symbologies that were not part of the display design. These were as follows: 1) all pilots preferred heading-up map orientation; 2) 50% of the pilots preferred the 60-sec predictor, as they felt it would provide more information more quickly and with less extrapolation. All pilots were concerned with the increased clutter resulting from the increased predictor length; 3) most pilots felt that of the viewing times examined, all but the 1 sec would be adequate.

PHASE 2

The primary objective of Phase 2 was to give the pilots the opportunity to compare their chosen display to those preferred by other pilots.

Independent Variables

Displays used in Phase 2 of this experiment were the displays chosen by the six pilots for task accuracy in Phase 1 (see table 4). Because three pilots chose the same display format, only four different display conditions were necessary. Two display formats (numbers 5 and 6) were added to enable

TABLE 3.- INITIAL DISPLAY FOR ACTUAL FLIGHT. ALL PILOTS CHOSE CONTINUOUS ROTATION AND TRANSLATION OF OWN-SHIP

	Pilot number					
	1	2	3	4	5	6
Background:						
none						
grid	X					X
flightpath		X	X	X	X	
Update rate:						
4 sec						
2 sec						
1 sec	X	X	X	X		
.1 sec					X	X
Predictor type:						
none	X				X	
straight						
curved (intruder)				X		
curved (both)		X	X			
relative						X
History type:						
none		X	X	X	X	
ground ref. (both)						X
ground ref. (intruder)	X					
relative						
% error task 1						
3000 ft miss distance	25	21	4	38	49	25
6000 ft miss distance	25	4	0	8	33	17

the experimenters to examine the issue of update type. These were similar to other displays preferred by pilots except for their different update types (see table 5).

Experimental Design

Six pilots viewed 24 encounters with each of the six display formats. Each display was presented once at a constant miss distance of 914 m (3000 ft). Presentation order of displays and encounters was random. A questionnaire was administered after completion of all display formats.

TABLE 4.- FINAL DISPLAY CHOICES FOR THE EXPERIMENTAL TASK.
ALL PILOTS CHOSE CONTINUOUS ROTATION AND TRANSLATION

	Pilot number					
	1	2	3	4	5	6
Background:						
none						
grid	X					X
flightpath		X	X	X	X	
Update rate:						
4 sec						
2 sec						
1 sec	X	X	X	X		
.1 sec					X	X
Predictor type:						
none					X	
straight						
curved (intruder)						
curved (both)	X	X	X	X		
relative						X
History type:						
none	X	X	X	X		
ground ref. (both)						X
ground ref. (intruder)					X	
relative						
% error task 2						
3000 ft miss distance	17	21	4	13	33	17
6000 ft miss distance	8	0	0	4	21	8

RESULTS

Table 6 indicates the percent error of each pilot on his own display as well as on the displays chosen by the other pilots. Pilot performance on his own display was not always better than on other displays; however, each pilot's performance on his own choice tended to be superior to that of other pilots using the same display.

An additional analysis was conducted on data from the second day of testing. There was a significant difference among display types ($F5, 25 = 10.38$, $p < 0.001$), and a significant interaction between display format and type of encounter, ($F5, 25 = 5.11$, $p < 0.01$). This supports the

TABLE 5.- DISPLAYS PRESENTED IN PHASE 2 OF THE EXPERIMENT. BECAUSE PILOTS 2, 3, AND 4 CHOSE THE SAME FORMAT, IT IS PRESENTED HERE AS DISPLAY 1. DISPLAYS 5 AND 6 HAD 1-SEC MAP ROTATION AND TRANSLATION WHILE DISPLAYS 1-4 WERE CONTINUOUS

	Display number					
	1	2	3	4	5	6
Background:						
grid		X		X	X	
flightpath	X		X			X
Update rate:						
1 sec	X	X			X	X
0.1 sec			X	X		
Predictor type:						
none			X			X
curved	X	X			X	
relative				X		
History type:						
none	X	X			X	
ground ref. (both)				X		
ground ref. (intruder)			X			

TABLE 6.- PERCENT ERROR FOR EACH PILOT FOR EACH DISPLAY. DISPLAYS STARRED ARE THE PILOT'S OWN CHOICES

	Display number					
	1	2	3	4	5	6
Subject 1	0	*0	25	21	4	33
2	*0	8	38	25	0	38
3	*0	4	25	21	8	25
4	*0	4	25	17	4	29
5	38	38	*38	33	25	25
6	17	25	33	*13	17	50

findings of previous research, which indicated that the use of predictors facilitates the perception of turning encounters (see table 7).

Multiple comparisons were conducted on: 1) curved predictors vs. history; 2) flightpath vs. grid; 3) continuous update vs. 1 sec update using history only; 4) continuous update vs. 1 sec update using curved predictors; and 5) curved predictors vs. relative predictors. Results indicated that

TABLE 7.- ANOVA ON DATA FROM PHASE 2
OVERDISPLAYS (A) AND ENCOUNTER TYPE (B)

Source	SS	df	MS	F
A (Display)	101.23	5	20.25	10.38^{***}
B (Encounter	3.12	1	3.12	3.63
S	50.07	5	10.01	
AXS	48.85	25	1.95	
BXS	4.29	5	.86	
AXB	42.47	5	8.49	5.11^{**}
AXBXS	41.62	25	1.66	

$^{***}p < 0.001$
$^{**}p < 0.01$

only the comparison of curved predictors vs. history reached significance, ($F1, 30 = 23.53$, $p < 0.001$). All other comparison were insignificant (see table 8).

TABLE 8.- MULTIPLE COMPARISONS ON PHASE 2 ANOVA
DATA OF DIFFERENT DISPLAY MEANS

Source	SS	df	MS	F
Treatment (A)	222.48	5		
comparison 1	155.04	1	155.04	23.53^{***}
comparison 2	2.08	1	2.08	<1
comparison 3	1.33	1	1.33	<1
comparison 4	2.08	1	2.08	<1
comparison 5	14.08	1	14.08	2.14
S/A	197.83	30	6.59	

$^{***}p < 0.001$

DISCUSSION

One of the purposes of this study was to determine if pilots would choose display symbologies which would enhance their ability to perceive encounters and so improve their judgment ability. Primary evidence for this would have been indicated by an insignificant difference between display types. In fact, significant differences were found between display types. However, all of the pilots but one performed best on the displays they designed.

As was found in previous research, encounters involving turning aircraft resulted in a higher incidence of error. Those displays using curved predictors alone had a significantly lower error rate than those using

ground-referenced history alone. Accuracy of judgment was greater with the larger miss distance of 1829 m (6000 ft), as compared to a smaller miss distance of 914 m (3000 ft).

Of special interest to the experimenters were the strategies reported by pilots for display interpretation. All six pilots chose either ground-referenced history or a type of predictor. Basically, the pilots wanted a prediction of aircraft motion, although they did not agree on how to display this information. Some pilots wanted the past motion displayed so they could do their own prediction, while others wanted a computer prediction based on current information. In this way, pilots used history alone to interpret encounter situations in the same manner as pilots using predictors alone.

All six pilots stated a preference for continuous rotation, translation, and update of own-ship (0.1 sec) as being aesthetically more appealing, less distracting, and enhancing their ability to perceive the relative motion of the intruder aircraft. There was no significant difference in performance between that type of update and one in which rotation was continuous and translation and update of own-ship was 1 sec. This may be due to the small time difference between 0.1 sec and 1.0 sec.

Three of the six pilots altered their display choices to improve task accuracy. Pilots tended to design more complex displays to improve task performance. Displays chosen for actual flight were generally less complex. Most pilots agreed on the need for minimal clutter on the display.

CONCLUSIONS

This experiment adds to a series of experiments designed to evaluate CDTI symbology in a dynamic but controlled environment. The following are general observations based on the data from the experiment.

> Despite differences in symbology preferred to display information, there appeared to be a consensus on the information considered necessary.

> The display variables with the greatest variability of preference were predictor and history.

> Pilots tended to make fewer errors on the perceptual task when using the display they designed.

> All pilots preferred continuous rotation, translation, and updating of the own-ship.

> A common concern of all the pilots was a display with all the needed information, but also one that was free from clutter.

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15. Supplementary Notes

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